ORIGINAL ARTICLES

Gait variability while dual-tasking: fall predictor in older inpatients?

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*ABSTRACT. **Background and aims:** Increased gait variability is associated with a high risk of falling in older community-dwellers, but no information exists about the relationship between increased gait variability and falls occurring in older hospitalized patients. We therefore sought to determine, in an acute geriatric setting, whether gait variability in single- (i.e., usual walking) or dual-task conditions can predict inpatient falls. **Methods:** Stride time variability was calculated in both single-task (i.e., usual walking) and dual-task conditions with a GAITRite®-System in 13 male and 44 female patients (mean age=85.0, SD=6.6 yrs) consecutively admitted to the acute care geriatric department of Geneva University Hospitals, Switzerland. All participants were able to walk without assistive devices at day 3 post-admission. Falls during hospital stay were identified through the hospital accident reporting system. **Results:** Ten fallers and 47 non-fallers were identified. The first fall events were significantly associated with the coefficient of variation of stride time in both walking conditions during hospital stay (OR 13.3, (95% CI 1.6-113.6),* p*=0.018 for usual walking; OR 8.6, (95% CI 1.9-39.6),* p*=0.006 for dual-task walking). Furthermore, the time elapsing between the first day of hospitalization and the first fall was significantly shorter when the cut-off value of stride time variability was calculated for dual-tasking compared with usual walking. The Cox regression model revealed that only the coefficient of variation of stride time during dual-task walking was significantly associated with the occurrence of the first fall event (*p*=0.006). **Conclusion:** Our results suggest that the degree of stride time variability in dual-task walking conditions distinguished fallers from non-fallers in a group of independently walking, older inpatients.*
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INTRODUCTION

Falls in older inpatients occur commonly, and often lead to a cascade of problems such as fractures and other injuries (1, 2), prolonged hospital stays (3), feelings of guilt among staff, and litigation (4). Several fall prevention programs have been shown to decrease the fall incidence in geriatric hospitals (5). In a recent systematic review of hospital fall prevention programs, Oliver et al. (6) found an intervention-related reduction in fall rates of 25%. Identifying patients at high risk of falling is the first step in designing targeted fall prevention programs (4, 6).

Falling usually results from elders' inability to adapt their gait patterns to unexpected situations (7, 8). Thus, new screening tools based on dual-task paradigms have been developed, comparing walking performance alone with walking while performing an attention-demanding task. Recently, clinical walking tests using dual tasking revealed a strong relationship between dual task-related gait changes and the risk for falling in older adults (9-13). However, ever since the first report by Lundin-Olsson et al. (9), who showed a link between the inability to walk and talk simultaneously and the occurrence of falls among older adults, the consistent prediction of falls by dual-task testing remains difficult. How attention is divided between two simultaneously performed tasks mainly depends on the efficiency of executive function (14, 15). Coppin et al. (16) found in 737 community-dwelling individuals aged 65 years and older that poor executive function is associated

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with low gait speed. Hausdorff et al. (14) also showed an association between low stride time variability and efficient executive function, and Sheridan et al. (15) reported a relationship between high stride time variability and impaired executive function - both powerful predictors of falling (14-18). Among the small number of fall risk factors consistently found in geriatric inpatients, gait instability was identified as one of the most important (6). However, in all inpatient studies, the diagnosis of unstable gait was always based on clinical impressions and arbitrary appreciation without any biomechanical quantification of the gait disorder. The subjectivity of visual observations has poor interrater reliability (19, 20) and does not give precise measures of gait such as gait variability (20).

No information exists on the relationship between increased gait variability and falls by geriatric inpatients, due to the limited length of the hospital stay. In contrast, high stride-to-stride variability ("irregular gait") while walking alone has been shown to be a powerful fall predictor in community-dwelling older adults (17, 18). In fact, a small increase in stride-to-stride variability in stride length of 0.017 m doubled the likelihood of future falling over the next 6 months (17). We recently reported that a dual task of walking and simultaneous backward counting significantly increased stride-to-stride variability in healthy older but not younger subjects (21). Therefore, we hypothesized that a dual task-dependent increase in stride-to-stride variability would prove to be a particularly sensitive method for identifying older subjects prone to falls.

However, the recent availability and growing number of validated, user-friendly portable gait analysis systems (22-26) allow simple quantitative gait measurements in older individuals, performed outside biomechanical gait laboratories in a more familiar environment with less technical equipment, lower costs, and less time required. Systematic quantification of gait in older inpatients during hospital stay may considerably enhance the quality of fall risk assessment by documenting obvious gait disorders and/or detecting subtle, specific fall-related gait changes, such as increased gait variability, particularly while dual-tasking.

The aims of this study were: 1) to quantify gait variability at admission in hospitalized geriatric patients in single- and dual-task walking conditions; and 2) to determine the relationship between gait variability and falls occurring during hospital stay for both these walking conditions.

METHODS

Participants

Fifty-seven out of 525 patients who were admitted to the Geneva geriatric hospital over a period of three months (from January to March 2003) were recruited for study inclusion by their referring nurse. Study inclusion criteria included the ability to walk more than 12 meters without an assistive device, willingness to participate, and a stable non-terminally ill health condition that allowed gait testing at day 3 after admission. Eight (7 non-fallers, 1 faller) of the 57 participants indicated intermittent use of a walking cane.

The choice of our highly selected patient group (i.e., able to walk without an assistive device) was motivated by the department's observation that unexpected falls occurred mainly in relatively mobile inpatients without severe locomotion problems. According to the policy of the geriatric hospital at Geneva University Hospitals, these patients are free to ambulate within the whole hospital area (e.g., cafeteria, entrance hall, park). Written informed consent was obtained from all patients before testing. The local ethics committee approved the project.

Setting

The geriatric hospital of the Geneva University Hospitals is an acute care facility with 300 beds serving patients aged 65 years and older (average age: 82.8 yrs). Due to a well-developed consultant system in internal and psychiatric medicine, reasons for admission are broad. In 2003, the five most frequent diagnoses on admission included, in decreasing order, pulmonary infections, renal failure, heart failure, dementia, and arterial hypertension.

Gait analysis procedures

Participants were asked to perform two different tasks: 1) usual walking (i.e., single task) and 2) usual walking while counting backwards by ones from 50 (i.e., dual task). Performance on the backward counting task alone was not assessed. The importance of walking and counting at the same time was emphasized to all participants, who were asked to walk and count at their very best without prioritizing either task. Possible counting mistakes were not corrected. Gait measurements were made according to the guidelines for clinical applications of spatio-temporal gait analysis in older adults (27). In brief, subjects completed one trial for each of the walking conditions on a 12-meter walkway in a well-lit environment, wearing their own footwear, and walking at a self-selected speed toward a visual target placed at the end of the walkway. To ensure safety, a fabric belt 7 cm wide was placed around each subject's waist, for easy grasp by a research assistant who walked beside the walkway, slightly behind the subjects, during all trials. Stride time in both walking conditions was determined during steady-state walking using a GAITRite®-System (GAITRite Gold, CIR Systems, PA, USA), (20, 22, 28, 29), consisting of a 10-m long carpet with an integrated, pressure-sensitive electronic surface of 7.32 x 0.61 m connected to a personal portable computer *via* an interface cable. The pressure-sensitive surface includes a series of sensors (total 13,824) placed every 1.27 cm, with their centers placed in a 48 x 288 grid, and activated by mechanical pressure. Data from the activated sensors are collected by a series of on-board processors and transferred to the computer through a serial port. Data are sampled from the carpet at a frequency of 80 Hz, allowing a temporal resolution of 12.5 ms. To measure steady-state gait, participants started walking at least two gait cycles prior to reaching the measuring electronic surface and stopped at least 2 gait cycles beyond it. We chose stride time variability as the main outcome gait parameter, given the published evidence of its strong relationship with falls in older adults (18). The testing procedures, including preparation, took between 5 and 10 minutes for each participant and were conducted by two trained physical therapists using standardized instructions. There were no instances of falls or near-falls during these trials.

Geriatric assessment

In the context of a routinely administered geriatric assessment at admission, all participants performed the Timed Up & Go Test (TUG) (30) and underwent cognitive assessment consisting of the Mini Mental Status Examination (MMSE) (31). These data, including details on patients' age, gender, length of hospital stay, number of chronic diseases, and medication were subsequently collected by the author by referring to patients' charts.

Falls assessment

A fall was defined as an involuntary change of posture, whereby a patient ended up lying on the floor. Falls were identified through the hospital accident reporting system. This system, implemented in the geriatric hospital at Geneva University Hospitals nine years ago, represents the statutory requirement to report all accidents occurring during hospital stay which include falls and patients found on the floor. The time between admission and fall was also recorded. Fallers and non-fallers were identified after discharge, based on the hospital's accident database in which falls are systematically reported (32).

Outcome measures

Primary outcome measurements were: 1) mean values and coefficients of variation of stride time (CV= [standard deviation / mean] x 100) while walking alone and while walking backwards counting, and 2) the first fall that occurred during hospital stay.

Table 1A - *Baseline characteristics of non-fallers and fallers, with univariate logistic regressions predicting occurrence of a first fall event.*

	Non-fallers (n=47)	**Fallers (n=10)**	***p****	**Crude OR (95% CI)**
Age [yrs] median (IQR)	84.0 (11.0)	86.5 (3.0)	0.200	1.1 (0.9-1.2)
Female (%)	37 (78.7)	7 (70)		0.6 (0.1-2.9)
Length of hospital stay [days] median (IQR)	24.0 (23.0)	26.5 (61.0)	0.881	4.9 (1.1-21.8)†
Number of chronic diseases	3.0 (2.0)	3.0 (0.0)	0.819	1.1 (0.6-1.9)
Number of drugs/day	3.5 (6.0)	3.5 (3.0)	0.777	0.9 (0.7-1.2)
Sedative medications, n (%)	26 (53.3)	4 (40.0)	0.492	2.8 (0.3-26.9)
Timed "Up & Go", median (IQR) (sec)	16.0 (10.0)	19.0±13.0	0.069	6.2 (0.9-41.3)
Mini Mental State Examination of Folstein (/30), median score (IQR)	24.0±6.0	17.0±12.0	0.091	0.8 (0.6-1.0)

*Based on Mann-Whitney U-test or Fisher's exact test, as appropriate, with *p* significant at <0.05. †Based on univariate logistic regression analysis, with *p* significant at <0.05. OR: Odds ratio; CI: Confidence interval; CV: Coefficient of Variation = ([standard deviation/mean] x 100).

Table 1B - *Stride time parameters of non-fallers and fallers, with univariate logistic regressions predicting occurrence of a first fall event.*

	Non-fallers (n=47)	**Fallers (n=10)**	***p****	**Crude OR (95% CI)**
Stride time while walking alone				
Number of stride median (IQR)	17.0 (7.0)	19.5 (8.0)	0.243	
min - max	12 - 37	13 - 30		
Mean value ± SD (sec)	1.2±0.2	1.2±0.1		1.2 (0.1-239.8)
median (IQR)	1.2 (0.3)	1.2 (0.1)	0.850	
CV (%)	5.3±4.6	7.8±5.6		2.7 (1.1-7.2)
median (IQR)	3.8 (3.1)	5.2 (3.4)	0.023	
Stride time while walking with backward counting				
Number of stride median (IQR)	17.0 (8.0)	19.0 (7.0)	0.535	
min - max	11 - 34	12 - 34		
Mean value (sec)	1.2±0.2	1.2±0.3		0.3 (0.2-6.3)
median (IQR)	1.2 (0.3)	1.2 (0.1)	0.883	
CV (%)	7.4±7.0	17.2±14.7		3.4 (1.3-8.5)†
median (IQR)	4.7 (4.8)	11.3 (24.8)	0.016	

*Based on Mann-Whitney U-test or Fisher's exact test, as appropriate, with *p* significant at <0.05. †Based on univariate logistic regression analysis with *p* significant at <0.05. OR: Odds ratio; CI: Confidence interval; CV: Coefficient of Variation = ([standard deviation/mean] x 100).

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Table 2A - *Risk estimates of a first fall event occurring during hospital stay, based on univariate logistic regression models.*

Variable	Walking alone		Walking backwards counting	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Coefficient of variation of stride time (coded as a binary variable)*	13.3 (1.6-113.6)	0.018	8.6 (1.9-39.6)	0.006

OR: odds ratio.
*Binary threshold determined by sensitivity analysis (coefficient of variation >4% while walking alone, coefficient of variation >10% while walking backwards counting).

Statistical analyses

Medians and interquartile ranges or frequencies and percentages, as appropriate, were used to describe the study participant characteristics (Table 1). The Mann-Whitney U-test or Fisher's exact test was used to compare subjects' baseline characteristics and stride time parameters, as appropriate. Motivated by the clinical need to determine an operational limit above which patients were declared at high fall risk, the coefficient of variation of stride time was coded *post-hoc* as a binary variable with a threshold determined by sensitivity analysis (coefficient of variation >4% while walking alone, coefficient of variation >10% while walking backwards counting). Sensitivity analysis consisted of building a receiver operator curve by computing the sensitivity and specificity of each CV value, to determine the most discriminant threshold maximizing both sensitivity and specificity, which was then used as a binary variable to plot Kaplan-Meier curves as well as repeating both logistic and Cox regression analyses. Univariate logistic regression analysis was performed to specify the relationships between the occurrence of first fall events during hospital stay and the binary value of the coefficient of variation in both walking conditions. The time elapsing to the first fall event was studied by survival curves computed according to the Kaplan-Meier method and compared by the log-rank test. Subjects were censored when they were discharged from the hospital. Univariate analysis based on Cox regression models was used to identify the most significant walking condition related to the delay of the first fall event. *p*-values of less than 0.05 were considered statistically significant. All statistics were performed using Stata Statistical Software: Release 9.2, College Station, Tx, USA: Stata Corp.

RESULTS

Baseline subjects' characteristics

A summary of selected patients' characteristics by fallers (n=10) and non-fallers (n=47) is shown in Table 1. Most of the fallers' characteristics were similar to those of non-fallers. In comparison to non-fallers, fallers had lower MMSE scores and took longer to perform the TUG, although these differences did not reach statistical significance (p=0.091, p=0.069, respectively). The only significant association found for predicting the occurrence of a first fall event was length of hospital stay (Crude OR 4.9 (95% CI 1.1-21.8), p=0.034).

Stride time parameters

As shown in Table 1, with regard to mean values, no significant differences were found between fallers and non-fallers in either walking condition. However, in contrast to non-fallers, fallers' coefficient of variation was significantly higher while walking alone (7.8±5.6 *vs* 5.3±4.6, p=0.023), and substantially increased while walking backwards counting (17.2±14.7 *vs* 7.4±7.0, p=0.016). The coefficient of variation of stride time while walking backwards counting was significantly associated with the occurrence of a first fall event (Crude OR 3.4 (95% CI 1.3-8.5), p=0.010), but did not reach significance for walking alone (Crude OR 2.7 (95% CI 1.0-7.2), p=0.055).

Relationship between occurrence of first fall events during hospital stay and coefficient of variation of stride time

As indicated in Table 2A, the occurrence of first fall events during hospital stay (mean follow-up 29.6±25.9 days) was significantly associated with the coefficients of variation of stride time, coded as binary variables, in both walking conditions (OR 13.3 (95% CI 1.6-113.6), p=0.018 for walking alone; OR 8.6 (95% CI 1.9-39.6), p=0.006 for walking backwards counting). The introduction of cut-offs for the CV was motivated by the clinical need to determine an operational limit above which patients were declared at high fall risk. The binary threshold was determined *post-hoc* using sensitivity analyses (CV>4% for walking alone, CV>10% for walking backwards counting). Interestingly, the 4% CV cut-off found for our study sample while walking alone supports previously reported data from community-dwelling older adults, in which the mean CV of fallers were identified at 4.1%, compared with 2.4% in non-fallers and 1.9% in young adults (22).

Kaplan-Meier estimates of the probability of falling during hospital stay according to the CV of stride time while walking alone and while walking backwards counting are shown in Figure 1. Due to missing fall time information for one faller and because two fallers fell during the evaluation day, the total number of subjects at day 1 (Time 0) was reduced to 54. In both walking conditions, Kaplan-Meier distributions of falls differed significantly between subjects with increased stride time *vs* normal stride time variability (p=0.027 when walking alone,

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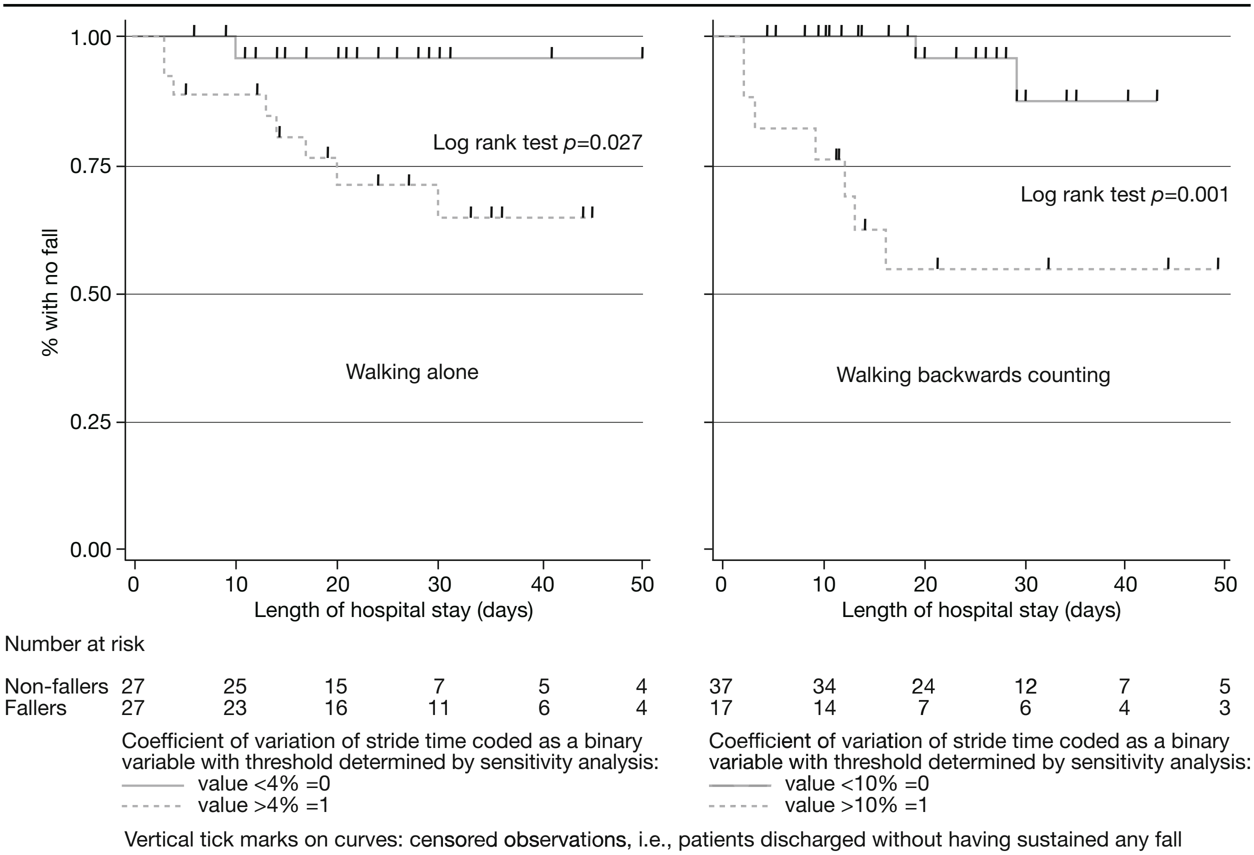

Fig. 1 - *Kaplan-Meier estimates of probability of falling during hospital stay, according to coefficient of variation of stride time while walking alone and while walking backwards counting, in 57 inpatients.*

p=0.001 when walking backwards counting). However, increased stride time variability while walking backwards counting identified more fallers within a shorter time-span than did increased stride time variability while walking alone. For instance, after 20 days of hospitalization, about 70% of patients were without falls when the CV was applied while walking alone, compared with about 55% when the CV was applied while walking and backwards counting. Thus, with dual-task walking as a testing tool, 15% more fallers were identified within the first 20 hospitalization days than with the CV while walking alone. The Cox regression model revealed that only CV of stride time while walking backwards counting was significantly associated with the occurrence of the first fall event during the hospital stay (Hazard Ratio (HR) 7.4 (95% CI 0.9-59.0), p=0.060 for walking alone; HR 9.1 (95% CI 1.9-43.8), p=0.006 for walking with backward counting) (Table 2B).

Table 2B - *Risk estimates of the time to a first fall event occurring during hospital stay based on univariate Cox regression models.*

Variable	**Walking alone**		**Walking backwards counting**	
	HR (95% CI)	***p*-value**	**HR (95% CI)**	***p*-value**
Coefficient of variation of stride time (coded as a binary variable)*	7.4 (0.9-59.0)	0.060	9.1 (1.9-43.8)	0.006

CI: confidence interval; HR: hazard ratio. *Binary threshold determined by sensitivity analysis (coefficient of variation >4% while walking alone, coefficient of variation >10% while walking backwards counting).

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DISCUSSION

Among a subgroup of selected older inpatients able to walk without walking aids, our study showed that increased stride time variability while walking at day 3 post-admission was associated with subsequent falls during the hospital stay. Further, increased stride time variability while dual-tasking detected more patients who fell within the first 20 hospitalization days than did increased stride time variability while walking alone. The data indicate that, among our selected group of inpatients, simplified quantitative dual-task gait evaluation, administered at day 3 after admission, represents an innovative and quick way of identifying patients at high short-term risk of falling.

Falls in geriatric facilities are common and associated with considerable morbidity and mortality (1-3). The common perception that falls should be preventable reinforces the view that "zero fall rates" in these settings are desirable and achievable (33). However, the reality is that falls can always happen in a setting in which patients are encouraged to mobilize and allowed to take reasonable risks (4). Therefore, when offering inpatient programs to prevent falls and/or fall-consequences, this reality always needs to be clearly communicated to patients and families, in order to avoid unrealistic expectations. Nevertheless, one out of four inpatient falls can be prevented (5), and the first important step in inpatient fall prevention is to identify high-risk patients at admission (34). Gait instability is one of the most common fall risk factors for hospital falls (6), but it is not always specifically assessed at admission. Therefore, systematically determining the risk of falling by having patients walk on a short electronic walkway at admission, as in the present study, may be a simple, efficient and particularly good illustrative way for patients, families and nursing staff to increase their awareness of potential falls during the hospital stay. In addition, the implementation of such a fall risk determination may improve active adherence to suggested interventions - for instance, wearing hip-protectors.

Increased stride-to-stride variability while walking alone has been associated with an increased risk of falling in community-dwelling older adults over 6 to 12 months (17-18), but not yet in geriatric inpatients during a much shorter observation period of 20 to 30 days. Our findings suggest that the association between increased gait variability and fall risk found in older community-dwellers is also valid in independently walking older inpatients during a much shorter observation period. Moreover, increased stride time variability while dual-tasking identified more short-term fallers than did increased stride time variability while walking alone. Only few data exist about dual task-related gait variability in older adults (15, 21, 35). In contrast to young adults, a small sample of older healthy adults demonstrated that coping with a simultaneous walking-associated attention-demanding task seemed to increase gait variability moderately (21). There is some evidence that stride-to-stride variability while walking alone increases with progressive cognitive decline in Alzheimer's disease (36). Further, Sheridan et al. (15) recently reported that deficits in divided attention increased gait variability in patients with Alzheimer's disease, finding a significant association between impaired executive function and increased gait variability in the dual-task walking condition but not walking alone. However, that study did not examine the relationship between increased dual task-related gait variability and fall risk. In our sample of independently walking geriatric inpatients, we were able both to establish a significant relationship between increased dual task-related gait variability and increased fall risk, and to identify a critical threshold for the stride time coefficient of variation (CV>10%) which was strongly associated with fall events in the patient group.

Changes in gait patterns due to the simultaneous performance of a walking-associated task have been reported previously and interpreted as attention interference in gait control (37). Older adults who stopped walking while talking were shown to be at a high risk of falling during the following six months (9). Recent reviews have shown that the current understanding of dual-task interference is that gait and a walking-associated task place competing demands on attention resources (37). Both tasks of walking and backward counting used in our dual-task paradigm are relatively easily performed, due to their low level of difficulty. Because a low level of task difficulty is associated with a low attention load (35), walking and backward counting do not necessitate major attention in young adults (38). However, there is growing evidence that gait control in healthy older adults requires more attention than in young adults (35, 37). Beauchet et al. (21) recently found that stride-to-stride variability moderately but significantly increased in a small group of healthy older adults while walking and simultaneous counting backwards. The moderate dual task-related gait variability increase found in healthy older, but not younger, adults was interpreted as a possible marker for age-related decline in motor control. The results of the current study suggest that significant dual task-related interference occurs in patients with stride time variability exceeding the identified critical threshold, possibly corresponding to an overload of available central attention resources and therefore potentially explaining the increased fall risk.

Our study has several limitations. First, due to the study design, the critical gait variability threshold for an increased fall risk during hospital stay could only be identified retrospectively. Therefore, based on this identified stride time variability threshold, the sensitivity and specificity of increased stride time variability for fall prediction in geriatric inpatients remain to be determined and validated in a prospective study design. Second, our results are not representative of geriatric inpatients in general, because the study sample was rather small and consisted only of a subgroup of inpatients who were able to walk without walking aids. The high follow-up variability within the sample of inpatients is another limiting setting-related particularity, caused by the prolonged hospital stays of inpatients who could not be transferred to nursing homes because of a lack of available beds in the Geneva area when the study was conducted. The generalizability of our data therefore seems restricted to specific geriatric rehabilitation units where mobility and gait disorders are common, obvious, and routinely assessed. Nevertheless, in non-geriatric hospital divisions without particular expertise in fall risk assessment, such as internal medicine, ophthalmology, dermatology, etc., determination of older inpatients' gait variability at admission may be a simple and efficient way of identifying patients at high fall risk and thus of improving fall prevention and the quality of care during hospital stay.

In conclusion, our study is the first to suggest that analysis of stride-to-stride variability while walking and simultaneous counting backwards at admission is both easy to perform and able to detect hospital fallers in a selected subgroup of independently walking older inpatients. Further research is needed to confirm these results in larger and more diverse populations of older inpatients, so as to facilitate the development of targeted interventions to prevent falls in inpatients at high risk.

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REFERENCES

1. Bates D, Pruess K, Souney P, Platt R. Serious falls in hospitalized patients; correlates and resource utilization. Am J Med 1995; 99: 137-43.
2. Vassallo M, Vignaraja R, Sharma JC, Briggs R, Allen S. The relationship of falls to injury among hospital in-patients. Int J Clin Pract 2005; 59: 17-20.
3. Vassallo M, Sharma JC, Allen SC. Characteristics of single fallers and recurrent fallers among hospital in-patients. Gerontology 2002; 48: 147-50.
4. Oliver D. Bed falls and bedrails-what should we do? Age Ageing 2002; 31: 415-8.
5. Oliver D, Hopper A, Seed P. Do hospital fall prevention programs work? A systematic review. J Am Geriatr Soc 2000; 48: 1679-89.
6. Oliver D, Daly F, Martin FC, McMurdo ME. Risk factors and risk assessment tools for falls in hospital inpatients: a systematic review. Age Ageing 2004; 33: 122-130.
7. Bloem BR, Steijns JA, Smits-Engelsman BC. An update on falls. Curr Opin Neurol 2003; 16: 15-26
8. Bloem BR, Valkenburg VV, Slabbekoorn M, Willemsen MD. The Multiple Tasks Test: development and normal strategies. Gait Posture 2001; 14: 191-202.
9. Lundin-Olsson L, Nyberg L, Gustafson Y. "Stops walking when talking" as a predictor of falls in elderly people. Lancet 1997; 349: 617.
10. Lundin-Olsson L, Nyberg L, Gustafson Y. Attention, frailty, and falls: the effect of a manual task on basic mobility. J Am Geriatr Soc 1998; 46: 758-61.
11. Verghese J, Buschke H, Viola L, et al. Validity of divided attention tasks in predicting falls in older individuals: a preliminary study. J Am Geriatr Soc 2002; 50: 1572-6.
12. Stalenhoef PA, Diederiks JP, Knottnerus JA, Kester AD, Crebolder HF. A risk model for the prediction of recurrent falls in community-dwelling elderly: a prospective cohort study. J Clin Epidemiol 2002; 55: 1088-94.
13. Bootsma-van der Wiel A, Gussekloo J, de Craen AJ, van Exel E, Bloem BR, Westendorp RG. Walking and talking as predictors of falls in the general population: The Leiden 85-Plus Study. J Am Geriatr Soc 2003; 51: 1466-71.
14. Hausdorff JM, Yogev G, Springer S, Simon ES, Giladi N. Walking is more like catching than tapping: gait in the elderly as a complex cognitive task. Exp Brain Res 2005; 164: 541-8.
15. Sheridan PL, Solomont J, Kowall N, Hausdorff JM. Influence of executive function on locomotor function: divided attention increases gait variability in Alzheimer's disease. J Am Geriatr Soc 2003; 51: 1633-7.
16. Coppin AK, Shumway-Cook A, Saczynski JS, et al. Association of executive function and performance of dual-task physical tests among older adults: analyses from the InChianti study. Age Ageing 2006; 35: 619-24.
17. Maki BE. Gait changes in older adults: predictors of falls or indicators of fear. J Am Geriatr Soc 1997; 45: 313-20.
18. Hausdorff JM, Rios DA, Edelberg HK. Gait variability and fall risk in community-living older adults: a 1-year prospective study. Arch Phys Med Rehabil 2001; 82: 1050-6.
19. Alexander NB. Gait disorders in older adults. J Am Geriatr Soc 1996; 44: 434-51.
20. Bilney B, Morris M, Webster K. Concurrent related validity of the GAITrite® walkway system for quantification of the spatial and temporal parameters of gait. Gait Posture 2003; 17: 68-74.
21. Beauchet O, Kressig RW, Najafi B, Aminian K, Dubost V, Mourey F. Age-related decline of gait control under a dual-task condition. J Am Geriatr Soc 2003; 51: 1187-8.
22. Cutlip RG, Mancinelli C, Huber F, DiPasquale J. Evaluation of an instrumented walkway for measurement of kinematic parameters of gait. Gait Posture 2000; 12: 134-8.
23. Aminian K, Najafi B, Bula C, Leyvraz PF, Robert P. Spatio-temporal parameters of gait measured by an ambulatory system using miniature gyroscopes. J Biomech 2002; 35: 689-99.
24. Moe-Nilssen R, Helbostad JL. Estimation of gait cycle characteristics by trunk accelerometry. J Biomech 2004; 37: 121-6.
25. Mayagoitia RE, Nene AV, Veltink PH. Accelerometer and rate gyroscope measurement of kinematics: an inexpensive alternative to optical motion analysis systems. J Biomech 2002; 35: 537-42.
26. Alexander NB. Using technology-based techniques to assess postural control and gait in older adults. Clin Geriatr Med 1996; 12: 725-44.
27. Kressig RW, Beauchet O. Guidelines for clinical applications of

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spatio-temporal gait analysis in older adults. Aging Clin Exp Res 2006; 18: 174-6.

28. Menz HB, Latt MD, Tiedemann A, Mun San Kwan M, Lord SR. Reliability of the GAITRite system for the quantification of temporo-spatial parameters of gait in young and older people. Gait Posture 2004; 20: 20-5.
29. McDonough AL, Batavia M, Chen FC, Kwon S, Ziai J. The validity and reliability of the GAITRite system's measurements: a preliminary evaluation. Arch Phys Med Rehabil 2001; 82: 419-25.
30. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 1991; 39: 142-8.
31. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975; 12: 189-98.
32. Loew F, Registe-Rameau Y, Kressig R, Marcant D, Herrmann F, Michel JP. Epidemiology of falls in a geriatric ward: rationale for a quality program. In: Michel JP, Hof PR, eds. Management of Aging. The University of Geneva Experience. Basel: Karger, 1999: 44-52.
33. McMurdo ME, Harper JR. Institutional falls: quality not quantity. Age Ageing 2004; 33: 399-400.
34. Oliver D. Prevention of falls in hospital inpatients: agendas for research practice. Age Ageing 2004; 33: 328-30.
35. Beauchet O, Berrut G. Gait and dual-task: definition, interest, and perspectives in the elderly. Psychol Neuropsychiatr Vieil 2006; 4: 215-25.
36. Nakamura T, Meguro K, Sasaki H. Relationship between falls and stride length variability in senile dementia of the Alzheimer type. Gerontology 1996; 42: 108-13.
37. Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. Gait Posture 2002; 16: 1-14.
38. Dubost V, Beauchet O, Herrmann F, Kressig RW. Stride-to-stride variability while backward counting among healthy young adults: Transversal study. J Neuroengineering Rehabil 2005; 2: 26.